



Sartini, C., Morris, R., Whincup, P. H., Wannamethee, S. G., Ash, S., Lennon, L., & Jefferis, B. J. (2017). Association of Maximum Temperature With Sedentary Time in Older British Men. *Journal of Physical Activity and Health*, 14(4), 265-269.  
<https://doi.org/10.1123/jpah.2016-0468>

Peer reviewed version

Link to published version (if available):  
[10.1123/jpah.2016-0468](https://doi.org/10.1123/jpah.2016-0468)

[Link to publication record in Explore Bristol Research](#)  
PDF-document

This is the author accepted manuscript (AAM). The final published version (version of record) is available online via Human Kinetics at <http://journals.humankinetics.com/doi/10.1123/jpah.2016-0468>. Please refer to any applicable terms of use of the publisher.

## University of Bristol - Explore Bristol Research

### General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available:  
<http://www.bristol.ac.uk/red/research-policy/pure/user-guides/ebr-terms/>

**Title:** Association of maximum temperature with sedentary time in older British men

**Manuscript types:** Original Research

**Key words:** sedentary behaviour; older adults; weather; epidemiology; accelerometry

**Abstract word count:** 200

**Manuscript word count (inclusive of all pages except the abstract and title page):** 3976

**Date of manuscript submission:** 18/10/2016

**Authors:** Claudio Sartini <sup>1,2\*</sup>, Richard W Morris <sup>1,3</sup>, Peter H Whincup <sup>4</sup>, S Goya Wannamethee <sup>1</sup>, Sarah Ash <sup>1</sup>, Lucy Lennon <sup>1</sup>, and Barbara J Jefferis <sup>1,2</sup>

<sup>1</sup> Department of Primary Care & Population Health, University College London, Rowland Hill Street, NW3 2PF, London. UK

<sup>2</sup> UCL Physical Activity Research Group (PARG), University College London, UK.

<sup>3</sup> School of Social & Community Medicine, University of Bristol, Canynge Hall, 39 Whatley Rd, Bristol BS8 2PS, UK.

<sup>4</sup> Population Health Research Institute, St George's University of London, Cranmer Terrace London SW17 0RE, UK.

\* Corresponding Author

E-mail: [c.sartini@ucl.ac.uk](mailto:c.sartini@ucl.ac.uk)

Telephone + 020 7830 2335

Fax: +44 207 794 1224

## Abstract

**Background:** Sedentary behaviour is very common in older adults and a risk factor for mortality. Understanding determinants of sedentary behaviour may help in defining strategies aimed to reduce the time spent sedentary. The degree of difference in sedentary time attributable to varying temperatures has not been yet estimated in older men.

**Methods:** Men aged 71-91 years participating in an established UK population-based cohort study were invited to wear an Actigraph GT3x accelerometer for one week in 2010-12. Outcome was sedentary time (<1.5 Metabolic Equivalent of Task) in minutes per day. Associations between daily outdoor maximum temperature and accelerometer-measured sedentary time were estimated using multilevel models.

**Results:** 43% (1361/3137) of invited men participated in the study and provided adequate data. Men spent on average 615 minutes in sedentary time per day (72% of the total accelerometer-wear time). After adjusting for covariates, men spent 26 minutes more per day ( $p<0.001$ ) in sedentary time when temperatures were in the lowest (-3.5; 9.2°C) versus highest quintile (19.1; 29.5°C).

**Conclusions:** Sedentary time in older adults is highest at lowest temperatures, typically recorded in winter. Findings are relevant for guidelines: interventions may consider targeting older men in winter providing recommendations for minimising sedentariness on daily basis.

## Background

A standard definition of sedentary behaviour has not yet been established, although contemporary researchers agree that sedentary behaviour is not simply a lack of physical activity.<sup>1</sup> Sedentary behaviour can be defined as the time spent in activities engendering less than 1.5 Metabolic Equivalent of Task (METs).<sup>2</sup> In recent years, there have been an increasing number of studies which have reported associations between prolonged sedentary behaviour and health outcomes, such as mortality and cardiovascular disease, which have been independent of physical activity levels<sup>3</sup>. Therefore, understanding determinants of sedentary behaviour may help in defining strategies aimed to reduce the time spent sedentary. This is particularly important in older adults, who are known as the most sedentary of all age-groups.<sup>4</sup>

A few previous studies in older adults have demonstrated that low outdoor temperatures were associated with less time spent in physical activity,<sup>5,6</sup> although an association with sedentary time was not investigated. We would intuitively expect sedentary time to be higher at lower temperatures, as occur during the winter season. However, the degree of difference in sedentary time attributable to varying outdoor temperatures has not been estimated in previous studies of older adults. Outdoor temperature has been overlooked in sedentary behaviour guidelines,<sup>7</sup> and as determinant of sedentary time.<sup>8,9</sup> To our knowledge an association of temperature with sedentary time in older adults has not been previously documented.

Considering the gaps in knowledge of previous research, we have therefore investigated how sedentary time (<1.5 METs) varies according to outdoor maximum temperature in a large UK population based cohort study of community-dwelling older men.

## Methods

## 69 *Participants*

70 The British Regional Heart Study (BRHS) is a prospective cohort of men recruited from a single local  
 71 primary care centre in 24 British towns in 1978-80.<sup>10</sup> In 2010-2012, the surviving participants  
 72 resident in the United Kingdom (UK), then aged 71-91, were invited to attend a further physical  
 73 examination and to participate in a study of objectively measured physical activity, on which the  
 74 analyses presented here are based. Men who met the inclusion criteria (not living in a residential  
 75 home and not being on wheelchair) were included. Participants completed a log diary (detailing  
 76 when the accelerometer was worn) and a comprehensive health status questionnaire. The  
 77 participants' individual characteristics and questionnaire data were already described elsewhere.<sup>11</sup>  
 78 The National Research Ethics Service Committee for London provided ethical approval. Participants  
 79 provided informed written consent to the investigation, which was performed in accordance with  
 80 the Declaration of Helsinki.

81

## 82 *Measurements and data analysis*

83 Repeated measures of physical activity levels per each participant were recorded over the course of  
 84 one week by using accelerometers. Methods for accelerometer-data extraction and processing were  
 85 previously described in detail,<sup>11</sup> and added here as supplementary material (see Supplementary  
 86 data, Appendix S1). In brief, the number of minutes per day in spent in sedentary behaviour, light  
 87 physical activity (LIPA) and moderate to vigorous physical activity (MVPA) was derived and  
 88 categorised using count-based intensity threshold values of counts per minute (CPM) developed for  
 89 older adults, as in previous studies; the cut-points used were <100, 100-1040, >1040 CPM for  
 90 sedentary time (<1.5 METs), time spent in LIPA (<1.5-2.9 METs) and MVPA (>=3 METs) respectively.  
 91 <sup>4,12,13</sup> Number of steps per day was also recorded as a measure of overall physical activity. Then,  
 92 maximum temperatures were linked to the accelerometer data for each day the men wore the  
 93 device. Daily temperatures (maximum and minimum), hours of sunshine, and relative humidity were  
 94 provided by the UK Meteorological (MET) Office (see Supplementary data , Appendix S1). Maximum

temperature was used as the main exposure variable and divided into quintiles. Quintiles were chosen as temperatures in the lowest quintile (1Q, -3.5°C; 9.2°C) were representative of the typical UK winter, while temperatures in highest quintile (5Q: 19.1°C; 29.5°C) were representative of the typical UK summer.<sup>14</sup> The main outcome investigated was sedentary time measured in minutes per day. In preliminary analysis, the correlations between sedentary time and other PA variables (steps, LIPA, and MVPA) were calculated. Linear multilevel models (level 1 was the date of wear and level 2 was the individual) with random intercept only were used to estimate associations between quintiles of maximum temperature and sedentary time. Quintiles of maximum temperature were derived counting every day each participant wore an accelerometer. The highest quintile of maximum temperature (5<sup>th</sup> quintile, 5Q) was chosen as reference quintile, and the results were reported as mean difference in sedentary time between the reference vs lower quintiles. As in one previous study,<sup>11</sup> the model was adjusted for measurement variables (accelerometer-wear time, wear day order [first day of wear, second, etc.], day of the week, age, social class, Body Mass Index (BMI), chronic conditions, mobility limitations, geriatric depression scale, vision problems, smoking status, and day length (a proxy for season)). The adjustment for day length was made to check whether there was confounding between temperature and a different seasonal term (collinearity was not observed as the Variance Inflation Factor (VIF) score was less than 1.5). As sensitivity analysis, a linear model was performed using maximum temperature as a continuous variable instead of the quintiles.

#### *Subsidiary analyses*

For completeness of information, we investigated associations of maximum temperature with different outcomes related to sedentary behaviour: total number of sedentary breaks per day, daily number of sedentary bouts of <30 minutes, and daily number of sedentary bouts of ≥30 minutes.

Associations of minimum temperature, hours of sunshine, and relative humidity (continuous variables) with sedentary time were also estimated.

A further investigation was performed to corroborate findings from previous studies which made use of different physical activity outcomes, rather than sedentary time. Therefore, associations of temperatures (maximum and minimum), hours of sunshine, and relative humidity with daily (i) number of steps, (ii) minutes spent in LIPA, and (iii) minutes spent in MVPA were estimated.

We also performed stratified analysis by excluding men who were depressed or/and with mobility limitations. All analyses were carried out using STATA/SE 13<sup>15</sup> and MLwiN Version 2.30.<sup>16</sup>

## Results

1455 (46%) surviving men participated and met the inclusion criteria. 1361 men (43.4%) had data on all covariates (complete case analysis) and they had same mean age (78.5 years, SD=4.6) and BMI (26.7, SD=3.3) in comparison with 1455 men who met the inclusion criteria. The 1361 men with complete data were used in the final analysis: men had a mean of 6.5 (SD = 1.2) valid days of accelerometer wear; they wore the accelerometer for 855 minutes per day (SD=93) and took on average 4872 steps per day (SD=2767). The average sedentary time per day was 615 minutes (SD=83), corresponding to 72% of the total accelerometer wear time; time spent in LIPA and MVPA was 198 minutes (SD=65) and 39 minutes (SD=32) respectively. The correlations between daily sedentary time with steps, LIPA, and MVPA were -0.46, -0.54, and -0.47 respectively (all p-values<0.001).

## *Descriptive statistics*

The median for maximum temperature in the lowest quintile was 6.3°C (between -3.5°C and 9.2°C) and in highest quintiles was 20.8°C (between 19.1°C and 29.5°C). In descriptive plots, unadjusted

sedentary time was highest when temperatures were in the lowest quintiles, and then decreased at higher temperatures (Figure 1).

#### *Associations between maximum temperatures and sedentary time*

The adjusted associations from multilevel models between quintiles of maximum temperature and sedentary time are shown in Table 1. In summary, lower temperatures were associated with more time spent in sedentary behaviour ( $p < 0.001$ ). In particular, men spent 26 minutes more per day (95%CI 19; 33) in sedentary time when temperatures were in the lowest compared with the highest quintile (Table 1). When analysing maximum temperature as continuous variable, a negative linear association with sedentary time was observed: a decrease in 1 SD ( $5.8^{\circ}\text{C}$ ) in maximum temperature was associated with an increase of 11 minutes per day (95%CI 8; 13) in sedentary time ( $p < 0.001$ ). The adjustment for day length did not alter the magnitude of these associations; day length was not significantly associated with sedentary time ( $p = 0.212$ ).

#### *Subsidiary analyses*

A decrease of 1 SD ( $5.8^{\circ}\text{C}$ ) in maximum temperature was associated with a decrease of 2 (95% CI 1; 3) breaks in sedentary time per day, and an increase of 0.2 (95%CI 0.1; 0.3) daily number of longer sedentary bouts ( $\geq 30$  minutes). No association was found between maximum temperature and daily number of shorter sedentary bouts ( $< 30$  minutes).

Variations in hours of sunshine and relative humidity were associated with variations in sedentary time. On the other hand, association of minimum temperature with sedentary time was not significant (Appendix S1, eTable 1).

Maximum temperature was also strongly associated with other physical activity outcomes: a decrease of 1 SD in maximum temperature was associated with -7 minutes in LIPA per day (95%CI -9;



-5), -4 minutes in MVPA per day (95%CI -5; -2), and -323 steps per day (95%CI -428; -218). Similarly, variations of hours of sunshine and relative humidity were also associated with variations of time spent in LIPA, MVPA, and steps per day, although the magnitude of associations was smaller.

Association of minimum temperature with physical activity was not significant (Appendix S1, eTable 1).

In stratified analysis, the magnitude of associations between temperature and sedentary time were not materially affected by excluding men who were depressed or/and with mobility limitations (Appendix S1, eTable 2).

## Discussion

In this large study of older British men, outdoor maximum temperature was associated with accelerometer-measured sedentary time: a decrease in maximum temperatures was associated with an increase in sedentary time after controlling for potential confounding variables (measurement variables, individual characteristics, and day length).

### *Overall findings*

The analysis of maximum temperature subdivided in quintiles offered a simple and intuitive interpretation of the results: during a typical winter day (temperature in the lowest quintile) older men spent 26 minutes more per day in sedentary time in comparison with a typical summer day (temperatures in the highest quintiles). Perception of cold may particularly inhibit older individuals from spending time outdoors. Apart from the discomfort and need to wear suitable clothing, there may be a fear of falling due to ice. Consequently, older adults may prefer replacing some incidental light physical activity outdoors (e.g. a gentle walk for pleasure) with sedentary behaviours indoors, such as television watching.<sup>17</sup>

We focused our investigation on maximum temperature as primary determinant as it is more accurate than other meteorological factors due to a lower spatial variability.<sup>18</sup> However, in subsidiary analysis we also demonstrated that less hours of sunshine and higher relative humidity, typical elements of the winter season in UK, were also associated with an increase in sedentary time. To our knowledge these findings are novel and not previously reported. Literature in this field is sparse; one small study of forty-six adults demonstrated that accelerometer-measured sedentary time is higher in winter than summer, although the participants were about 40 years younger than our population.<sup>19</sup> The majority of the studies investigated children or adolescents, which are known to have a different life-style in comparison with older adults.<sup>20</sup>

#### *Strengths and limitations*

This study used data from the BRHS, which is a large scale population-based cohort of older men, rather than an institutionalised older population. The magnitude of associations between temperature and sedentary time were not materially affected by excluding men who were depressed or/and with mobility limitations. Thanks to accelerometers it was possible to overcome problems of recall error, which is known to be more common in older individuals.<sup>21</sup> Therefore, an objective measure is more accurate and recommended, considering the proportion of time older adults spent in sedentary behaviours.<sup>22</sup> Moreover, we corroborated previous findings which have investigated accelerometer-measured physical activity outcomes: as in earlier studies we showed that low maximum temperatures, fewer hours of sunshine, and higher relative humidity were associated with fewer steps per day, and less time spent in LIPA and MVPA.<sup>5,6</sup> We also demonstrated that the association of maximum temperature with physical activity was strongest in comparison with associations of sunshine duration and humidity with physical activity. Our findings suggested that maximum temperature is the most important predictor of physical activity in the UK. However, earlier studies which took place in Germany, Scotland and Japan had identified a range of different meteorological factors as being the most important, such as global radiation<sup>23</sup>, day length and

diurnal minimum temperature<sup>5</sup>, rainfall and mean temperature.<sup>24,25</sup> However, we would expect that, as in our results, radiation and other temperature variables are positively correlated with maximum temperature.

The study have some limitations: men who did not accept our invitation to participate in the study were about two years older and had higher BMI measured 10 years earlier; implying that overall physical activity (e.g. total number of steps) might be lower in the general population. Our study is also limited by studying almost exclusively white European older men, who would be expected to spend more time in sedentary behaviour, compared with younger individuals.<sup>4</sup> Moreover, our results may not be generalizable to women, or to other ethnic groups.<sup>26</sup>

We defined sedentary behaviour based solely on intensity, rather than intensity and posture (more widely used), as this study did not aim to investigate the “type” of sedentary behaviours (e.g. sitting at a computer, lying on the couch, driving, etc.). However, the activity monitors we used provide useful estimates of sedentary time, as they have minimal bias in comparison with other devices able to detect intensity, position and posture.<sup>27</sup> The importance of position and posture is widely recognized and future studies could further investigate the particular types of sedentary behaviours (e.g. watching TV) carried out during the lowest peaks of activity.

Also, during the study period maximum temperatures never reached levels above 30°C. At those high temperatures, more typical of warmer climate zones than the UK, sedentary time may start to increase. During heat waves local authorities tend to alert older individuals, who are usually asked to remain indoors in the heat of the day, to get some rest and sit when necessary, and not engage in strenuous activities.

## Implications

The results may have important implications for guidelines. The UK recommendations suggest that older adults should aim to minimise the time they spend being sedentary each day<sup>8</sup>. Our findings provided more justification for minimising sedentary behaviours particularly at low temperatures, a typical element of the winter season. Replacing some of the time spent in sedentary behaviours into more active behaviours may have beneficial effects on health. However, to find ways to reduce sedentariness is challenging, as in modern life opportunities for sedentary behaviours are everywhere. To date, findings from the ProActive65+ trial suggested that older adults with poor self-rated health, higher BMI and history of smoking are more likely to reduce the sedentary time from an exercise intervention.<sup>28</sup> On the other hand, it is likely that interventions targeting individuals' psychological and environmental barriers (beliefs, feelings, and perspectives on participations in physical activity) may be a valid alternative for replacing sedentary time with more active behaviours.<sup>29,30</sup> Providing recommendations for simple do-it-yourself exercises (e.g. standing up or walking while watching TV, toe rises, calf and chest stretching) could be helpful. In older individuals, simple targets can make the reduction in sedentary behaviour easier to achieve and relevant on a daily basis.<sup>31</sup> Also, providing physically and economically accessible indoor opportunities for promoting more active behaviours during winter should be encouraged.

The temperature-related variation in sedentary time observed in this study could be relevant to the temperature-related variation in mortality risk.<sup>32</sup> It is plausible that persisting low temperatures in winter (primary determinant) may be a contributing factor which increases the sedentary time, as well as other risk factors levels [e.g. inflammatory markers, such as C-Reactive Protein and Interleukin-6<sup>33</sup>, contributing to the excess of winter mortality.<sup>34</sup> We estimated an increase of 26 minutes in sedentary time at lower versus higher temperatures. According to previous studies in older adults, replacing 30 minutes of sedentary time with light physical activity was independently associated with a significant reduction in mortality risk (HR = 0.80).<sup>35</sup> However, future investigations

are needed to establish how temperature-related variations in sedentary time may contribute to the temperature-related variations in mortality risk.

## **Conclusions**

In this study of older adults, we demonstrated that sedentary time increased at lower maximum temperatures. These findings are relevant for guidelines: interventions may consider targeting older adults in winter, when temperatures are lower, providing recommendations for minimising sedentariness on a daily basis.

**Competing Interests:** The authors have no competing interests to report.

## **Authors contributions**

**Study concept and design:** Whincup, Wannamethee, Jefferis

**Acquisition of data (outdoor temperature and accelerometers):** Morris, Whincup, Wannamethee, Jefferis, Ash, Lennon

**Analysis and interpretation of data:** Sartini, Morris, Whincup, Wannamethee, Jefferis.

**Drafting the article:** Sartini.

**Revising the article critically for important intellectual content:** Sartini, Morris, Whincup, Wannamethee, Ash, Lennon, Jefferis.

**Final approval of the version to be published:** Sartini, Morris, Whincup, Wannamethee, Jefferis, Ash, Lennon, Jefferis.

**Acknowledgements and funding sources:** The British Regional Heart study is supported by a British Heart Foundation programme grant (RG/08/013/25942). This research was supported by an NIHR Post-Doctoral Fellowship (2010–03–023) awarded to BJ and by British Heart Foundation grants (PG/13/41/30304 and PG09/024). The funders had no role in the design, methods, subject

301 recruitment, data collections, analysis or preparation of the paper. The views expressed in this  
302 publication are those of the author(s) and not necessarily those of the Funders. The authors thank  
303 the United Kingdom Meteorological Office for providing the weather data.

304

305

306

## References

- 307 1. Gibbs BB, Hergenroeder AL, Katzmarzyk PT, Lee IM, Jakicic JM. Definition, measurement, and  
308 health risks associated with sedentary behavior. *Med Sci Sports Exerc.* 2015;47(6):1295-  
309 1300.
- 310 2. Pate RR, O'Neill JR, Lobelo F. The evolving definition of "sedentary". *Exercise and sport*  
311 *sciences reviews.* 2008;36(4):173-178.
- 312 3. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, Alter DA. Sedentary Time and  
313 Its Association With Risk for Disease Incidence, Mortality, and Hospitalization in AdultsA  
314 Systematic Review and Meta-analysisSedentary Time and Disease Incidence, Mortality, and  
315 Hospitalization. *Annals of Internal Medicine.* 2015;162(2):123-132.
- 316 4. Jefferis BJ, Sartini C, Lee I-M, Choi M, Amuzu A, Gutierrez C, Casas J, Ash S, Lennnon L,  
317 Wannamethee S, Whincup P. Adherence to physical activity guidelines in older adults, using  
318 objectively measured physical activity in a population-based study. *BMC Public Health.*  
319 2014;14(1):382.
- 320 5. Witham MD, Donnan PT, Vadiveloo T, Sniehotta FF, Crombie IK, Feng Z, McMurdo MET.  
321 Association of Day Length and Weather Conditions with Physical Activity Levels in Older  
322 Community Dwelling People. *PLoS ONE.* 2014;9(1):e85331.
- 323 6. Prins RG, van Lenthe FJ. The hour-to-hour influence of weather conditions on walking and  
324 cycling among Dutch older adults. *Age Ageing.* 2015;44:886-890.
- 325 7. Australian Department of Health. Australia's Physical Activity and Sedentary Behaviour  
326 Guidelines. From [http://www.health.gov.au/internet/main/publishing.nsf/content/health-](http://www.health.gov.au/internet/main/publishing.nsf/content/health-pubhlth-strateg-phys-act-guidelines#apaadult)  
327 [pubhlth-strateg-phys-act-guidelines#apaadult](http://www.health.gov.au/internet/main/publishing.nsf/content/health-pubhlth-strateg-phys-act-guidelines#apaadult). 2014.
- 328 8. UK Department of Health PA, Health Improvement and Protection "Sedentary Behaviour and  
329 Obesity: Review of the Current Scientific Evidence". From  
330 [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/213745/d](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/213745/dh_128225.pdf)  
331 [h\\_128225.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/213745/dh_128225.pdf). 2010.
- 332 9. Chastin SFM, Buck C, Freiburger E, Murphy M, Brug J, Cardon G, O'Donoghue G, Pigeot I,  
333 Oppert JM. Systematic literature review of determinants of sedentary behaviour in older  
334 adults: a DEDIPAC study. *International Journal of Behavioral Nutrition and Physical Activity.*  
335 2015;12(1):1-12.
- 336 10. Walker M, Whincup P, Shaper A. The British Regional Heart Study 1975–2004. *International*  
337 *Journal of Epidemiology.* 2004;33(6):1185-1192.
- 338 11. Sartini C, Wannamethee SG, Iliffe S, Morris RW, Ash S, Lennon L, Whincup PH, Jefferis BJ.  
339 Diurnal patterns of objectively measured physical activity and sedentary behaviour in older  
340 men. *BMC Public Health.* 2015;15:609.
- 341 12. Copeland JL, Esliger DW. Accelerometer assessment of physical activity in active, healthy  
342 older adults. *J Aging Phys Act.* 2009;17(1):17-30.
- 343 13. Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc.  
344 accelerometer. *Med Sci Sports Exerc.* 1998;30(5):777-781.
- 345 14. UK Meteorological Office. Temperature, rainfall and sunshine time-series (1910-2015). From  
346 <http://www.metoffice.gov.uk/climate/uk/summaries/actualmonthly>. 2015.
- 347 15. [Software] Stata/SE 14 for windows [computer program]. College Station, Texas 77845 USA;  
348 2014.
- 349 16. [Software] MLwiN Version 2.30. Centre for Multilevel Modelling, University of Bristol.  
350 [computer program]. 2005.
- 351 17. O'Connell SE, Griffiths PL, Clemes SA. Seasonal variation in physical activity, sedentary  
352 behaviour and sleep in a sample of UK adults. *Annals of human biology.* 2014;41(1):1-8.

18. Hubbard KG. Spatial variability of daily weather variables in the high plains of the USA. *Agricultural and Forest Meteorology*. 1994;68(1):29-41.
19. O'Connell SE, Griffiths PL, Clemes SA. Seasonal variation in physical activity, sedentary behaviour and sleep in a sample of UK adults. *Annals of human biology*. 2014;41(1):1-8.
20. Hjorth M, Chaput JP, Michaelsen K, Astrup A, Tetens I, Sjodin A. Seasonal variation in objectively measured physical activity, sedentary time, cardio-respiratory fitness and sleep duration among 8-11year-old Danish children: a repeated-measures study. *BMC Public Health*. 2013;13(1):808.
21. Cumming RG, Klineberg RJ. A Study of the Reproducibility of Long-Term Recall in the Elderly. *Epidemiology*. 1994;5(1):116-119.
22. Jefferis BJ, Sartini C, Ash S, Lennon LT, Wannamethee SG, Whincup PH. Validity of questionnaire-based assessment of sedentary behaviour and physical activity in a population-based cohort of older men; comparisons with objectively measured physical activity data. *Int J Behav Nutr Phys Act*. 2016;13(1):14.
23. Klenk J, Buchele G, Rapp K, Franke S, Peter R, Acti FESG. Walking on sunshine: effect of weather conditions on physical activity in older people. *J Epidemiol Community Health*. 2012;66(5):474-476.
24. Aoyagi Y, Shephard RJ. Sex differences in relationships between habitual physical activity and health in the elderly: practical implications for epidemiologists based on pedometer/accelerometer data from the Nakanojo Study. *Arch Gerontol Geriatr*. 2013;56(2):327-338.
25. Togo F, Watanabe E, Park H, Shephard RJ, Aoyagi Y. Meteorology and the physical activity of the elderly: the Nakanojo Study. *International journal of biometeorology*. 2005;50(2):83-89.
26. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc*. 2008;40(1):181-188.
27. Healy GN, Clark BK, Winkler EAH, Gardiner PA, Brown WJ, Matthews CE. Measurement of Adults' Sedentary Time in Population-Based Studies. *American journal of preventive medicine*. 2011;41(2):216-227.
28. Heseltine R, Skelton DA, Kendrick D, Morris RW, Griffin M, Haworth D, Masud T, Iliffe S. "Keeping Moving": factors associated with sedentary behaviour among older people recruited to an exercise promotion trial in general practice. *BMC Family Practice*. 2015;16:67.
29. Bauman A, Merom D, Bull FC, Buchner DM, Fiatarone Singh MA. Updating the Evidence for Physical Activity: Summative Reviews of the Epidemiological Evidence, Prevalence, and Interventions to Promote "Active Aging". *The Gerontologist*. 2016;56(Suppl 2):S268-S280.
30. Chastin SFM, De Craemer M, Lien N, Bernaards C, Buck C, Oppert J-M, Nazare J-A, Lakerveld J, O'Donoghue G, Holdsworth M, Owen N, Brug J, Cardon G. The SOS-framework (Systems of Sedentary behaviours): an international transdisciplinary consensus framework for the study of determinants, research priorities and policy on sedentary behaviour across the life course: a DEDIPAC-study. *International Journal of Behavioral Nutrition and Physical Activity*. 2016;13(1):1-13.
31. Gardner B, Smith L, Aggio D, Iliffe S, Fox KR, Jefferis BJ, Hamer M. 'On Your Feet to Earn Your Seat': update to randomised controlled trial protocol. *Trials*. 2015;16(1):1-5.
32. Fowler T, Southgate RJ, Waite T, Harrell R, Kovats S, Bone A, Doyle Y, Murray V. Excess winter deaths in Europe: a multi-country descriptive analysis. *European journal of public health*. 2015;25(2):339-345.
33. Halonen JI, Zanobetti A, Sparrow D, Vokonas PS, Schwartz J. Associations between outdoor temperature and markers of inflammation: a cohort study. *Environmental health : a global access science source*. 2010;9:42.



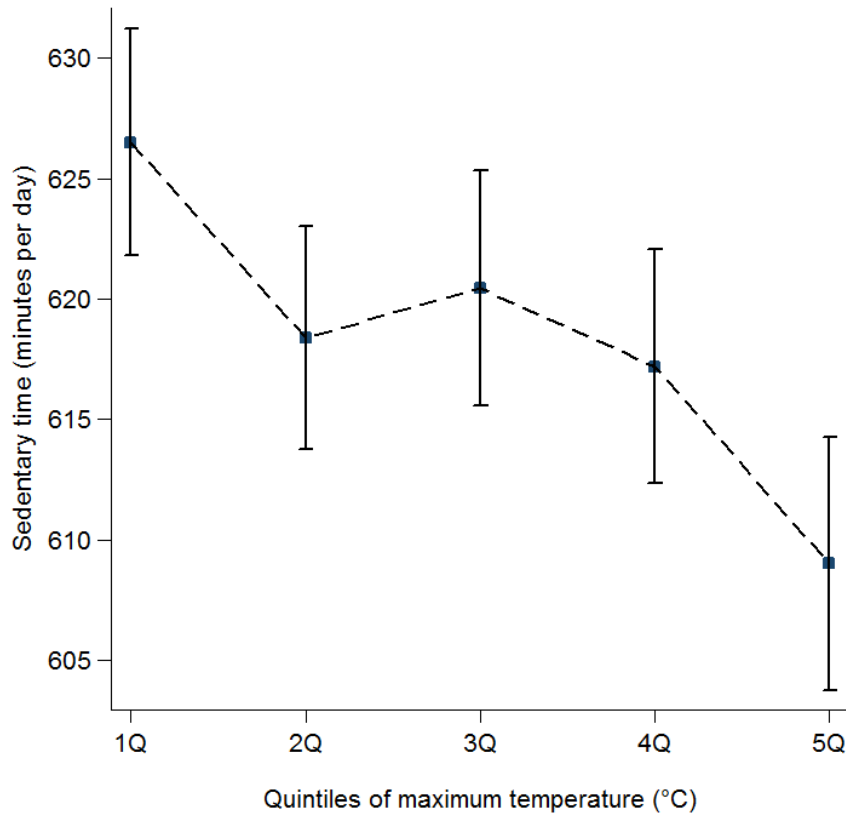
34. Sartini C, Barry SJE, Wannamethee SG, Whincup PH, Lennon L, Ford I, Morris RW. Effect of cold spells and their modifiers on cardiovascular disease events: evidence from two prospective studies. *International Journal of Cardiology*. 2016.
35. Fishman EI, Steeves JA, Zipunnikov V, Koster A, Berrigan D, Harris TA, Murphy R. Association between Objectively Measured Physical Activity and Mortality in NHANES. *Med Sci Sports Exerc*. 2016;48(7):1303-1311.

**Table 1 – Adjusted associations between quintiles (Q) of maximum temperature and sedentary time (n=1361) <sup>1</sup>**

Quintiles of maximum temperature (°C)	Mean difference (95%CI) in sedentary time (minutes per day)
5Q (19.1; 29.5), reference	-
4Q (16.6; 19.0)	+7 (3; 11)
3Q (13.1; 16.5)	+14 (10; 19)
2Q (9.3; 13.0)	+21 (15; 27)
1Q (-3.5; 9.2)	+26 (19; 33)
	p-value for trend<0.001

<sup>1</sup> Multilevel regression models (level 1=date, level 2= individual) adjusted for age, social class, BMI, chronic conditions, mobility limitations, geriatric depression scale, vision problems, smoking status, daily wear time, day of the week, wear day order, and day length

417 **Figure 1. Raw data (n=1361). Plots depicting relationship between sedentary time (mean, 95% CI),**  
 418 **and quintiles (Q) of maximum temperature <sup>1</sup>**



419  
 420 <sup>1</sup> Quintiles of maximum temperature were derived counting every day each participant wore an  
 421 accelerometer (median, minimum and maximum): 1Q: 6.3(-3.5,9.2); 2Q: 11.0(9.3,13.0); 3Q:  
 422 15.3(13.1,16.5); 4Q: 17.9(16.6,19.0); 5Q: 20.8(19.1,29.5). P-value for the difference between the  
 423 quintiles was  $p < 0.001$ .

424

## Appendix S1

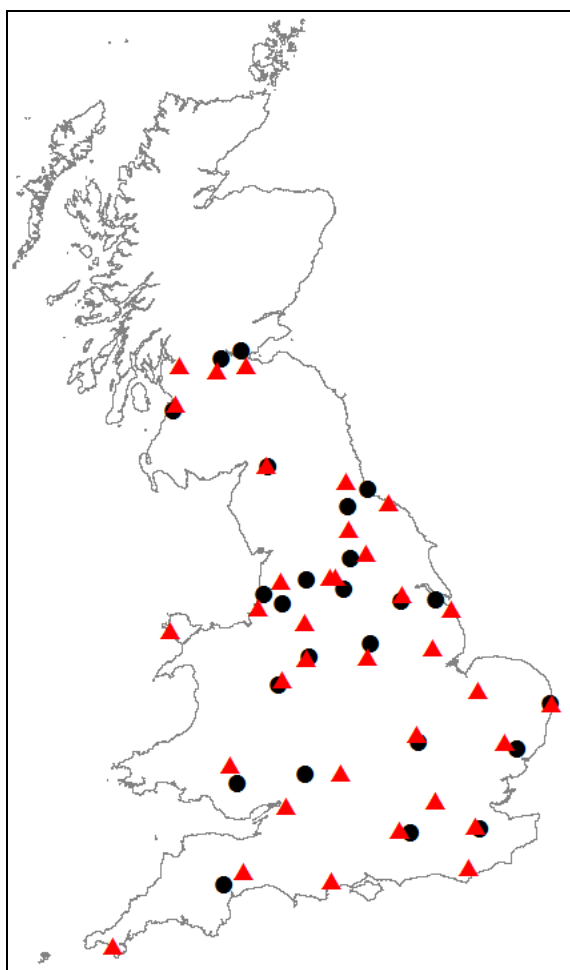
*Objectively measured sedentary behaviour and physical activity assessment*

All men who attended an assessment at their local primary care centre were asked to wear the Actigraph GT3x accelerometer (Pensacola, Florida) over the right hip on an elasticated belt for 7 days, during waking hours, removing it only for bathing, swimming or showering and returning the device by post. The study participants wore the accelerometer in between May 2010 and July 2012. The total number of men (by month) who wore the accelerometer was: n=93(6.8%) in January, n=145(10.7%) in February, n=150(11.0%) in March, n=30(2.2%) in April, n=115(8.5%) in May, n=121(8.9%) in June, n=152(11.2%) in July, n=43(3.2%) in August, n=150(11.0%) in September, n=170(12.5%) in October, n=166(12.2%) in November, 26=1.9% in December. Actigraph accelerometers record physical activity “counts” and steps, which both depend upon the frequency and intensity of the raw acceleration. First, to separate non-wear time from wear time, a sensitivity analysis was carried out using 3 different algorithms (‘non-wear time windows’ of 120, 90 and 60 minutes of zero counts) in a sample of 100 randomly selected men. We compared the self-reported wear time (when the men reported putting on and taking off the accelerometer) to the wear time derived from algorithms using 3 different non-wear time windows. The difference between self-report and algorithm wear time was -8, -1 and +28 minutes for non-wear time window of 120, 90 and 60 minutes respectively. The algorithm which made use of the non-wear time window of 90 minutes performed best; therefore we used that option for the overall population. In detail, non-wear time was identified and excluded using the R package “Physical Activity”<sup>1</sup>, based on (i) periods of continuous zero activity lasting more than 90 minutes or (ii) periods of zero activity lasting more than 90 minutes broken only by non-zero counts lasting up to 2 minutes, provided no activity counts were detected during both the 30 minutes before and after that interval<sup>2</sup>. Valid wear days were defined as  $\geq 600$  minutes wear time, and participants with at least 3 valid days were included in analyses, a conventional requirement for estimating usual PA level<sup>3</sup>. The number of minutes per day in spent in sedentary behaviour, light physical activity (LIPA) and moderate to vigorous physical activity (MVPA) was also derived and categorised using count-based intensity threshold values of counts per minute (CPM) developed for older adults, as in previous studies; the cut-points used were  $<100$ , 100-1040,  $>1040$  CPM for sedentary time ( $<1.5$  METs Metabolic Equivalent of Task), time spent in LIPA ( $<1.5$ - $2.9$  METs) and MVPA ( $\geq 3$  METs) respectively<sup>2,4,5</sup>.

*Meteorological factors*

Meteorological data for each day the men wore the accelerometer were taken from 35 weather stations via the United Kingdom (UK) Meteorological Office network (see Supplementary Figure 1 below). The participants resident in 24 UK towns were matched with the closest weather station via post code of residence (mean distance approximately 10 kilometres). The Meteorological Office provided daily temperatures (maximum and minimum between 09:00 h and 21:00 h), daily hours of sunshine (between 00:00 h and 23:59 h), and relative humidity (at 9am). Additionally, day length was provided and measured as hours of light during the day (from sunrise to sunset). Not all weather stations covered the entire follow-up period, so the few missing temperature data (<1.5%) were imputed using the nearest stations' values and linear regression modelling, as in previous studies <sup>6</sup>.

**Supplementary Figure 1** – United Kingdom map which indicates the 24 BRHS towns locations (black circles), and 35 MET stations locations (red triangles)



**eTable 1 – Adjusted associations of meteorological factors with sedentary time and physical activity levels. All estimates are reported as mean difference in the outcome levels per a decrease in 1 standard deviation in meteorological factors levels**

Meteorological factor <sup>1</sup>	Outcome	mean difference (95% CI) <sup>2</sup>
MAX temperature (°C)	Sedentary time <sup>3</sup>	11(8,13)
MIN temperature (°C)		2(-1,5)
Sunshine duration (hours)		9(8,11)
Relative Humidity (%)		-6(-8,-4)
MAX temperature (°C)	Time spent in LIPA <sup>4</sup>	-7(-9,-5)
MIN temperature (°C)		-1(-4,1)
Sunshine duration (hours)		-6(-7,-5)
Relative Humidity (%)		4(3,5)
MAX temperature (°C)	Time spent in MVPA <sup>5</sup>	-4(-5,-2)
MIN temperature (°C)		-1(-2,1)
Sunshine duration (hours)		-3(-4,-2)
Relative Humidity (%)		2(1,3)
MAX temperature (°C)	Number of steps	-323(-428,-218)
MIN temperature (°C)		-63(-166,41)
Sunshine duration (hours)		-270(-326,-213)
Relative Humidity (%)		187(122,251)

<sup>1</sup> For maximum temperature, minimum temperature, sunshine duration, and relative humidity the standard deviation is 5.8, 5.3, 3.7, and 13.2 respectively. Maximum temperature is defined as the highest air temperatures of the day (from 9am to 9pm); Minimum temperature is the lowest air temperatures of the day (from 9am to 9pm); Relative humidity is a single value recorded every day at 9am; Hours of sunshine were recorded from 00:00 - 23:59 of each day. Pearson correlations ( $p < 0.001$ ) of maximum temperature with minimum temperature is  $r = 0.93$ , of maximum temperature with sunshine duration is  $r = 0.45$ , of maximum temperature with relative humidity is  $r = -0.43$ .

<sup>2</sup> Multilevel regression models (level 1=date, level 2= individual) adjusted for age, social class, BMI, chronic conditions, mobility limitations, geriatric depression scale, vision problems, smoking status, daily wear time, day of the week, wear day order, and day length

<sup>3</sup> Sedentary time is at least one minute where the accelerometer registers values  $< 100$ cpm

<sup>4</sup> Time spent in Light physical activity (LIPA) is at least one minute where the accelerometer registers values between 100-1040cpm

<sup>5</sup> Time spent in Moderate to vigorous physical activity (MVPA) is at least one minute where the accelerometer registers values over 1040 CPM

**eTable 2 – Adjusted associations between quintiles (Q) of maximum temperature and sedentary time in the (i) overall population (n=1361); (ii) excluding participants with depression (n=1071); (iii) excluding participants with any mobility limitations (n=887), excluding participants with depression and with any mobility limitations (n=771).**

	Model 1 All, n=1361	Model 2 Excluding men with depression, n=1071	Model 3 Excluding men with mobility limitations, n=887	Model 4 Excluding men with depression and with mobility limitations, n=771
Quintiles of maximum temperature (°C)	Mean difference (95%CI) in sedentary time (minutes per day)	Mean difference (95%CI) in sedentary time (minutes per day)	Mean difference (95%CI) in sedentary time (minutes per day)	Mean difference (95%CI) in sedentary time (minutes per day)
5Q (19.1; 29.5), reference	-	-	-	-
4Q (16.6; 19.0)	+7 (3; 11)	+5 (1; 10)	+8 (3; 14)	+8 (2; 13)
3Q (13.1; 16.5)	+14 (10; 19)	+13 (8; 19)	+18 (12; 24)	+18 (11; 25)
2Q (9.3; 13.0)	+21 (15; 27)	+20 (13; 26)	+24 (17; 32)	+22 (14; 30)
1Q (-3.5; 9.2)	+26 (19; 33)	+24 (15; 32)	+28 (19; 37)	+25 (14; 35)

Model 1: Multilevel regression models (level 1=date, level 2= individual) adjusted for age, social class, BMI, chronic conditions, mobility limitations, geriatric depression scale, vision problems, smoking status, daily wear time, day of the week, wear day order, and day length

Model 2 = adjusted as Model 1 but omitting geriatric depression scale

Model 3 = adjusted as Model 1 but omitting mobility limitations

Model 4 = adjusted as Model 1 but omitting geriatric depression scale and mobility limitations

507

- 508 1. Choi L, Liu Z, Matthews C, Buchowski M. [Computer program] Process Physical Activity  
509 Accelerometer Data. November 2011; <http://cran.r-project.org/web/packages/PhysicalActivity/>.
- 510 2. Jefferis BJ, Sartini C, Lee I-M, Choi M, Amuzu A, Gutierrez C, Casas J, Ash S, Lennnon L,  
511 Wannamethee S, Whincup P. Adherence to physical activity guidelines in older adults, using  
512 objectively measured physical activity in a population-based study. BMC Public Health.  
513 2014;14(1):382.
- 514 3. Hart T, Swartz A, Cashin S, Strath S. How many days of monitoring predict physical activity  
515 and sedentary behaviour in older adults? Int J Behav Nutr Phys Act. 2011;8:62.
- 516 4. Copeland JL, Esliger DW. Accelerometer assessment of physical activity in active, healthy  
517 older adults. J Aging Phys Act. 2009;17(1):17-30.
- 518 5. Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc.  
519 accelerometer. Med Sci Sports Exerc. 1998;30(5):777-781.
- 520 6. Basagana X, Sartini C, Barrera-Gomez J, Dadvand P, Cunillera J, Ostro B, Sunyer J, Medina-  
521 Ramon M. Heat waves and cause-specific mortality at all ages. Epidemiology. 2011;22(6):765-772.

522

523